

THE WORLD OF CHEMISTRY

Program #12

WATER

Producer Robert Kaper

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

THE WORLD OF CHEMISTRY

Program #12: Water
Producer Robert Kaper
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Water, bathing,
forests, ocean liner, earth,
waves, water in a glass,
ice cubes, waterfall

NARRATOR (MUSIC and NAT
SOUND under):

The chemical we're most familiar with is the strangest substance on earth. It forms solutions that can dissolve solid rock, yet it's gentle enough to saturate the tissues of every living thing. Its molecular mass is less than most of the gases in air, yet it's normally a liquid dense enough to float a tanker. It's extremely rare on every other planet in the solar system, yet it's one of the commonest compounds on earth. It's water, and it's the strangest chemical of all.

SUPER: WATER

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

MONTAGE: Streams and rivers, irrigation, flowers, stalactite & stalagmite formation, rain, plants, fish, drinking water, dam, fountain, factory

NARRATOR (MUSIC and NAT SOUND under):

There's so much water around us, we take its unusual characteristics for granted. In fact, water's oddest trait is the one that's most familiar. It's a liquid at normal temperatures. The presence of a large amount of liquid water has had a profound effect on Planet Earth. Constantly circulating masses of water moderate extremes of temperature and make the planet livable. In plants, water reacts with carbon dioxide to form glucose, the source of energy for all life. Water dissolves so many things it's called the universal solvent. Plants are 95 percent water, fish 80 percent, and humans 65 percent, so all living things need a continuous supply. Because of water's unique characteristics, we put it to plenty of other uses. In fact, we use it far more than any other substance on earth. The annual consumption in the U.S. for all purposes is 2 million gallons per person. Eighty percent of the world's water is used in agriculture. In industry, we use it to transfer heat and as a chemical reactant and solvent.

MONTAGE: Dead fish,
polluted water, sludge,
chemist in lab, fishing,
microscopic shot

NARRATOR (MUSIC and NAT
SOUND under):

But remarkable properties can create difficulties. Because it's a liquid, water can pick up large amounts of contaminating particles, and since it's a good solvent, it can dissolve potentially harmful chemicals. As the earth's population grows, we add more and more contaminants, from industry, human waste, and sediment runoff. A major challenge facing the world of chemistry is to find better ways to clean up the water that we use, and more efficient ways to use the water that we have. To do that, we must first understand the chemistry behind the odd behavior of this unusual substance.

RH in park

ROALD HOFFMANN (SYNC):

My friends know that I'm the kind of guy who always carries around molecules in this back pack. You never know when they might come in handy. Here, for instance, is a nitrogen molecule, one component of the atmosphere. It's got a molecular mass of 28 grams per mole. Now, here is an oxygen molecule, the more important component to us of the atmosphere.
(cont.)

ROALD HOFFMANN cont:

It has a molecular mass of 32 grams per mole. Let's see what else I've got. Carbon dioxide, the molecule we exhale. It's a bit heavier, but still a light gas, with a molecular mass of 44 grams per mole. But here is a molecule which has a molecular mass of only 18 grams per mole. It's water. It's lighter than any of these other molecules which are gases, and yet, as you know, it's not a gas, it's a liquid. What is it that makes water so special? It can't be just the atoms in it, oxygen and hydrogen, because we have other molecules which contain those atoms and which don't have the properties of water. It must be the special combination of the atoms with each other, their arrangement in space, the disposition of the electrons in them, which gives this molecule, this molecule that is so important to us, its special properties.

GRAPHIC: The bonding
of H₂O in different states

NARRATOR (MUSIC under):

Water molecules are polar. Oxygen has a much stronger attraction for electrons than hydrogen does. So the electrons in each bond spend more time near the oxygen atom than they do near the hydrogen atoms. The oxygen atom, with two pairs of unbonded electrons, carries a partial negative charge. (cont.)

NARRATOR cont:

The two hydrogen atoms carry a partial positive charge. Each positive charge is concentrated in a tiny exposed hydrogen nucleus. When a positive hydrogen nucleus of one molecule comes near the negative pole of another molecule, they're attracted to each other. This attraction forms a hydrogen bond. Hydrogen bonds between molecules are not as strong as the covalent bonds that hold molecules together. But it takes far more energy to break apart molecules held by hydrogen bonds than to separate other molecules of similar size and mass. Below zero-degree Celsius, hydrogen bonds lock water molecules together into solid ice. As the temperature rises to zero, molecular motion increases and some of the hydrogen bonds are broken. Groups of molecules slide over each other and the solid form becomes a liquid. It remains a liquid over a wide temperature range. At 100 degrees Celsius, molecular motion becomes so rapid that the hydrogen bonds are broken completely, the molecules fly off and become a gas.

MONTAGE: Lake, seals on ice, snow capped mountains, streams, windsurfer, fish, ocean, glaciers, floating ice, whales

NARRATOR (MUSIC and NAT SOUND under):

Water occurs as a gas at the same time it's found in both the liquid and solid states. That's fortunate for us, because if some of the water on earth didn't evaporate into a gas, it wouldn't rain or snow, and we depend on rain and snow to replenish the fresh water needed for drinking, agriculture, and industry.

Although water's found nearly everywhere on earth, 97 percent of it is a salt solution. Less than one percent is fresh water we can use. Most fresh water is locked up in glaciers and Arctic ice caps. But ice does provide one benefit. It floats and insulates the water underneath from freezing. Ice floats because of another of water's unusual properties. The solid form is lighter than the liquid. If ice were heavier than liquid water, it would sink and stay frozen. Most of the water on earth would turn solid, with drastic consequences for all life.

DS in kitchen

DON SHOWALTER (SYNC):

Water is a constant part of our life.
We're taking it in all day long. We take
water to extract tea from tea leaves.
And coffee. Coffee is extracted from
coffee beans. And soft drinks and hard
drinks, they're really just water
solutions. Fruits and vegetables are just
about all water. Let me show you.
Take this orange and cut it, you can see
the juice in there. Lots of water in
fruits and vegetables in there for sure.
And we use water for cleaning, and
certainly for cooking. And now I want
to show you something. Bring this glass
in here, and take a cube and drop it in
there. Wow! Now this is water. See the
ice floating. Look what happened here.
Have you ever seen solid sink to the
bottom like that? It looks pretty bizarre,
doesn't it?

Two glasses from lab
demonstration

NARRATOR (NAT SOUND under):

The liquid on the left is an organic
solvent. A frozen cube of it sinks
because the solid form is denser than the
liquid.

DS in kitchen

DON SHOWALTER (SYNC):

When substances cool, when they get colder, the molecules slow down, and they get closer together. They pull in closer together. So the solid is more dense than the liquid, and so the cube should sink in its own liquid. The water doesn't act this way. As it freezes, it becomes less dense, it expands. Let me show you some proof of that. A full bottle of water put in the freezer will break. Why? As water goes from the liquid to the solid, it expands. Now, this is the only substance I can think of that does this.

GRAPHIC: The structure of ice

NARRATOR (MUSIC under):

As water's temperature decreases, its molecules slow down and begin to form additional hydrogen bonds. As they lock together, the molecules orient themselves farther apart than they were in the liquid state. They form a six-sided open pattern, a solid. The solid -- ice -- is less dense than the liquid. So ice floats on liquid water.

MONTAGE: Shots of snowflakes, snow falling, snow making machines, skiers, chemists working in labs, microscopic shots of ice crystals forming

NARRATOR (MUSIC and NAT SOUND under):

Frozen water molecules form the most beautiful shapes, snowflakes.

Snowflakes condense directly from water vapor in the air at below freezing temperatures. Making snowflakes is big business. Ski resorts around the world depend on snowmaking machines to keep the slopes covered when nature fails.

Until recently, the temperature had to be below freezing to make artificial snow.

But a technology has been developed to make snow at several degrees above freezing. It's called the Snomax process. A protein from bacteria helps to arrange water molecules into ice. Under the microscope, crystals take shape as the protein makes it easier for hydrogen bonds to lock the molecules together.

On the ski slopes, freeze-dried bacteria are added to water that goes into snowmaking machines, and fluffy white crystals come out. Frozen water is relatively pure, even ice from frozen salt water. When water molecules link together to form ice crystals, they leave other substances behind.

MONTAGE: Rain, clouds
over ocean, streams,
flowing water

NARRATOR (MUSIC and NAT
SOUND under):

Rain water is also relatively pure. When water molecules evaporate into a gas, they leave behind whatever was dissolved in them. But even raindrops contain dissolved gases absorbed from the air. They also pick up dust particles on their way down. And once they hit the ground, they pick up much more. Water acquires a lot of dissolved material: organic compounds from plants and animals, and inorganic minerals. These substances dissolve in water as individual molecules or ions. That is, they form solutions.

GRAPHIC: Water as a
solvent

NARRATOR (MUSIC under):

Water's unique ability to dissolve many different substances is due to its polarity and its ability to form hydrogen bonds. We can represent water molecules in a more compact form to show how they dissolve sodium chloride. Ionic compounds, such as sodium chloride consist of alternating positive and negative ions. Water's relatively positive hydrogen atoms attach to the negative chloride ions and pull them out of the crystal. (cont.)

NARRATOR cont:

And the relatively negative oxygen atoms attach to the positive sodium ions and pull them out of the crystal. The forces of water's attraction are stronger than the forces holding the sodium chloride ions together. When all ions have been pulled out of the crystal, the salt is dissolved. It's in solution with water.

DS in kitchen

DON SHOWALTER (SYNC):

Now here I already have a solution, liquor. It's a solution of ethyl alcohol in water. It's 80 proof. That means 40 percent alcohol and 60 percent water. Now, how does alcohol dissolve in water?

GRAPHIC: Water as a solvent

NARRATOR (MUSIC under):

Water molecules are polar and form hydrogen bonds. Ethyl alcohol molecules are also polar, and they also form hydrogen bonds. When ethyl alcohol mixes with water, it dissolves. The opposing poles of alcohol and water are attracted to each other, and the water and alcohol molecules also form hydrogen bonds with each other.

DS in kitchen

DON SHOWALTER (SYNC):

Water is called the universal solvent because so many things dissolve in it. But there are some substances that do not dissolve in water. Look what happens here. If I pour water into this liquid, watch what happens. There's two layers, and no matter how much I shake it, they still don't mix. They'll separate back out to those same two layers that's in there. How come? Well, the water is composed of polar molecules, whereas the other liquid is composed of nonpolar molecules of relatively high molecular weight. And because these two liquids are not alike, they won't mix.

GRAPHIC: Liquids
insoluble with water

NARRATOR (MUSIC under):

Water dissolves molecular substances that resemble it in size, polarity, and hydrogen bonding ability. Larger, nonpolar molecules that don't form hydrogen bonds are insoluble in water. An insoluble liquid mixed with water stays in a separate layer.

Chemist working
in lab

NARRATOR (NAT SOUND under):
Chemists have learned how to make such molecules soluble by adding ionic or polar portions to them. They can now make brand new water based products out of normally insoluble molecules. It's a technique used to modify natural polymers, long chains made of smaller molecules linked together. Dr. George Brode directs water-soluble polymer research for Union Carbide.

INTERVIEW: Dr. George Brode, director of water-soluble polymer research, Union Carbide

SUPER: George Brode

DR. GEORGE BRODE (SYNC):
We come in contact with the results of water-soluble polymers every day of our lives. For example, a latex paint that you use on your house, or to coat your walls, the stability of that depends on a water-soluble polymer. Personal care and medical products that are essential to us every day are based on water-soluble polymers.

MONTAGE: Chemist working in lab, crabs, surgery, streams, children playing under water-fall, drinking water, cleaning with soap, factory shots, wastewater discharge, water treatment plants, chemical dumps

NARRATOR (NAT SOUND under):
Dr. Brode has modified cellulose -- plant fiber -- so it will dissolve in water. The water-soluble cellulose is made into a gel that's used to open up clogged formations in oil wells. He's also figured out a way to take chitin, the polymer in crab shells, and make it dissolve in water. Potential uses for soluble chitin includes surgical sutures and blood anticoagulants. Water's solvent ability lets it dissolve a wide range of molecules, whether we want it to, or not. It can dissolve minerals, and pick up calcium, magnesium and iron ions. They're responsible for the hard water that tastes bad, reacts with soap to form an insoluble scum, and forms mineral deposits in pipes and hot water heaters. Water's dissolving ability makes it vital as an industrial material. Industry needs it as a solvent for a wide range of chemical reactions. Most of the water industry uses is discharged back into the environment, but before waste water can be returned to a river or lake, it first has to be cleaned. (cont.)

NARRATOR cont:

Treatment plants hold dirty water in settling tanks so large particles can sink to the bottom. Bacteria are then introduced to digest the remaining organic materials. Proper treatment removes enough contaminants so that the water can be safely returned to the environment. But not all waste water is properly treated, and undesirable substances still get into lakes and rivers, the main source of our drinking water. Further problems arise from leaking storage tanks and chemical dumps. Some of these substances are suspected carcinogens, which can cause cancer. So Senator David Durenberger has authored legislation to control carcinogenic contaminants that had been unregulated.

INTERVIEW: Senator David
Durenberger, Minnesota

SUPER: Senator David
Durenberger

SEN. DAVID DURENBERGER
(SYNC):

This is a large group of chemicals whose presence in our water supply caused us deep concern. As our ability to diagnose, detect, becomes more refined, our knowledge and our understanding of the potential danger also expanded it.

Drinking fountain,
water fountain

NARRATOR (NAT SOUND under):
The Federal Government has set limits
on the levels of such chemicals, but
critics argue that the limits are stricter
than what's needed to protect our health.
Geraldine Cox is a vice president of the
Chemical Manufacturers Association.

INTERVIEW: Geraldine Cox,
Vice President, Chemical
Manufacturers Association

SUPER: Geraldine Cox

GERALDINE COX (SYNC):
I think just because the material is there
doesn't mean it's harmful. I mean today
I know that I ate carcinogens. I ate
mushrooms with my omelet this
morning. I had basil with the omelet.
At lunch I had a hamburger. And all of
those had known carcinogens. Am I
afraid? No, I ate them.

Shots of water treatment
plant: cleaning, testing,
analyzing

NARRATOR (MUSIC and NAT
SOUND under):
All chemicals are toxic at some level.
The open question is what levels pose
unacceptable health risks? Contaminants
in drinking water are trapped with
chemicals and filtered out by hard coal
and sand. The last treatment step is
disinfection to kill bacteria. (cont.)

NARRATOR cont:

That's usually done with chlorine, or, in some cases, with ozone gas bubbled through the water. Disinfection is the main reason most water-borne diseases have been eliminated in this country. The water has been tested to make sure it meets government standards for cleanliness. But even the most modern treatments don't remove everything, and that's where the argument lies. Just how clean must our water be before it's considered safe? Modern analytical instruments can detect concentrations lower than one part of chemical in one billion parts of water. The limit for the chemical benzene, for example, is 5 parts per billion. Should we play it safe and set limits at these low concentrations or even lower, or could we set them higher without any additional danger?

INTERVIEW: Senator David Durenberger cont.

SEN. DAVID DURENBERGER
(SYNC):

We have learned things repeatedly that tell us that our standards have been too lax. Lead, to me, is the best example, at least from my experience here over the last few years with lead. We used to tolerate some incredibly high amount of lead in water and in the air. (cont.)

SEN. DAVID DURENBERGER cont:
But today, we have banned lead from our gasoline. We are working on lead as one of the incredibly difficult problems in our drinking water system. And we've reduced -- we've increased the standards for lead very substantially on the basis of new knowledge.

INTERVIEW: Geraldine Cox cont.

GERALDINE COX (SYNC):
I think the criteria that we're using are the right ones. I think we need to be a little more realistic in setting the levels that we're dealing with. The goals for a carcinogen in drinking water are zero. But in some cases that may actually increase the risk of cancer. I'll give you an example, selenium. Selenium is a known carcinogen based on laboratory studies. If we -- but yet, if water doesn't have a certain amount of selenium, people drinking that water actually have a higher incidence of cancer. So at low levels it's an anti-carcinogen, at high levels it's a carcinogen.

INTERVIEW: Senator David Durenberger cont.

SEN. DAVID DURENBERGER (SYNC):
About everything we deal with in terms of the quality of drinking water has to do with chemists and chemistry. (cont.)

SEN. DAVID DURENBERGER cont:
Our wonderful chemists have created these problems for us; our wonderful chemists are hard at work in helping us detect and define these problems and they're also being asked to help us solve these problems.

INTERVIEW: Geraldine Cox cont.

GERALDINE COX (SYNC):
There have been contaminated wells. There have been hazardous waste sites contaminating material. And there have been releases of materials that shouldn't have gotten into the environment. That's all behind us. We are working very hard to clean up the environment, to reduce our emissions, to reduce the amount of contaminants. We have a responsibility to work, to protect the environment and the health of people around us. But so does everyone.

MONTAGE: Drinking from water fountain, chemist working in lab, wastewater, lake

NARRATOR:
Controversy about drinking water will continue. Hard choices will have to be made about acceptable levels of contamination, for new detection methods are bound to uncover more potentially toxic substances. Yet there is optimism. (cont.)

NARRATOR cont:

The quality of our water will improve because of a science that is responsible and creative and because of a public that is well-informed and active.

SUPER: WATER

MONTAGE: Shots of water in nature, in the home and in industry, program graphics

NARRATOR (MUSIC under):

To review: Water's unusual characteristics set it apart from all other substances. Based on its molecular mass, it should be a gas, yet it's a liquid at normal temperatures. Its solid form is less dense than the liquid. And it's able to dissolve a wide range of other substances, including the vital chemicals needed for life and those used in many industrial reactions. The water molecule have partial positive charges at one end and a partial negative charge at the other, so it can form hydrogen bonds with itself and with many other substances. Water's properties make it vulnerable to contamination from industry and human waste. These contaminants have to be removed from waste water before it's returned to the environment, and from drinking water before we put it into our bodies.

RH in park

ROALD HOFFMANN (SYNC):

Why water in the laboratories, in our bodies? Well, first of all, a liquid is best, better than a gas or a solid for transporting matter or running a chemical reaction. A gas is too dispersed, it's difficult to get anything transported with a gas. And a solid is rigid, it's difficult to mix liquids and gases with it. A liquid is just right. It's movable, deformable, and it's no wonder that there are slurries and solutions running down the pipelines of our factories, just as there are in our bodies, in arteries, in veins, in the intercellular space. Okay. So a liquid. But why water? Well, water is the universal solvent. It dissolves ionic solids, transporting through our body sodium, potassium, phosphate, and it also dissolves non-ionic molecules, sugars, alcohols, and acids. Water is also attuned to the temperature of the planet. It is a liquid under most normal conditions, a solid or gas at the extremes. Waters, teaming with life, covers 70 percent of this world. Perhaps we should have called this planet, not Earth, but Ocean.

Credits, Closing Montage, Closing Music

Copyright © 1988
Educational Film Center
and The
University of Maryland

The World of Chemistry Logo

A Production of
UNIVERSITY OF MARYLAND
AND
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo